Processing flexible glass
Thin film stress and its influence on glass durability

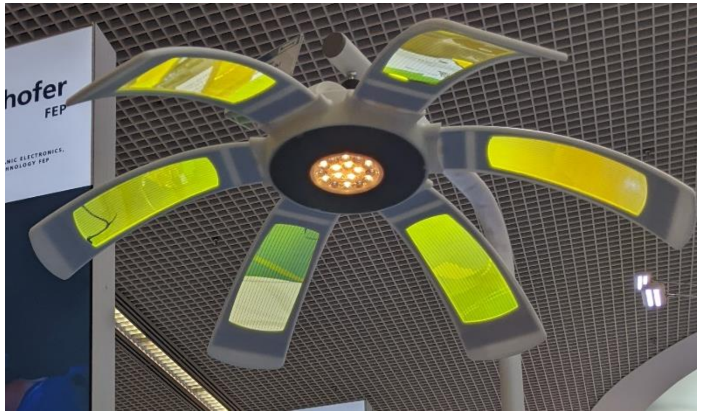
W. Langgemach[1], G. Lorenz[2], K. Täschner[1], F. Naumann[2], T. Preußner[1], M. Ott[1]

[1]Fraunhofer FEP, Dresden
[2]Fraunhofer IMWS, Halle

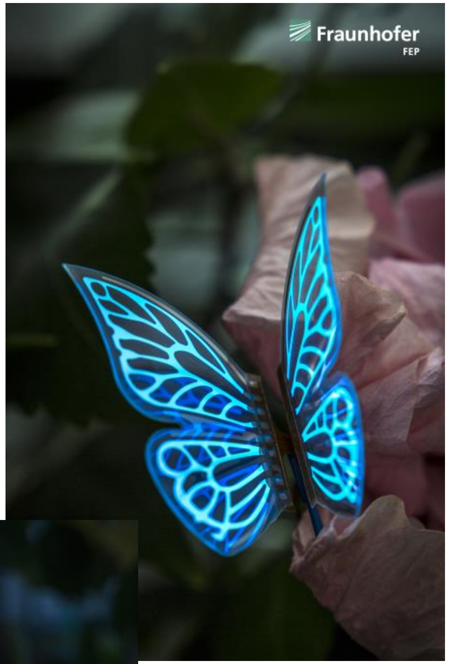
26/04/2023, Session 7: Reliability of organic electronics

Glass with thicknesses below 100 µm is flexible

Flexible glass has outstanding characteristics



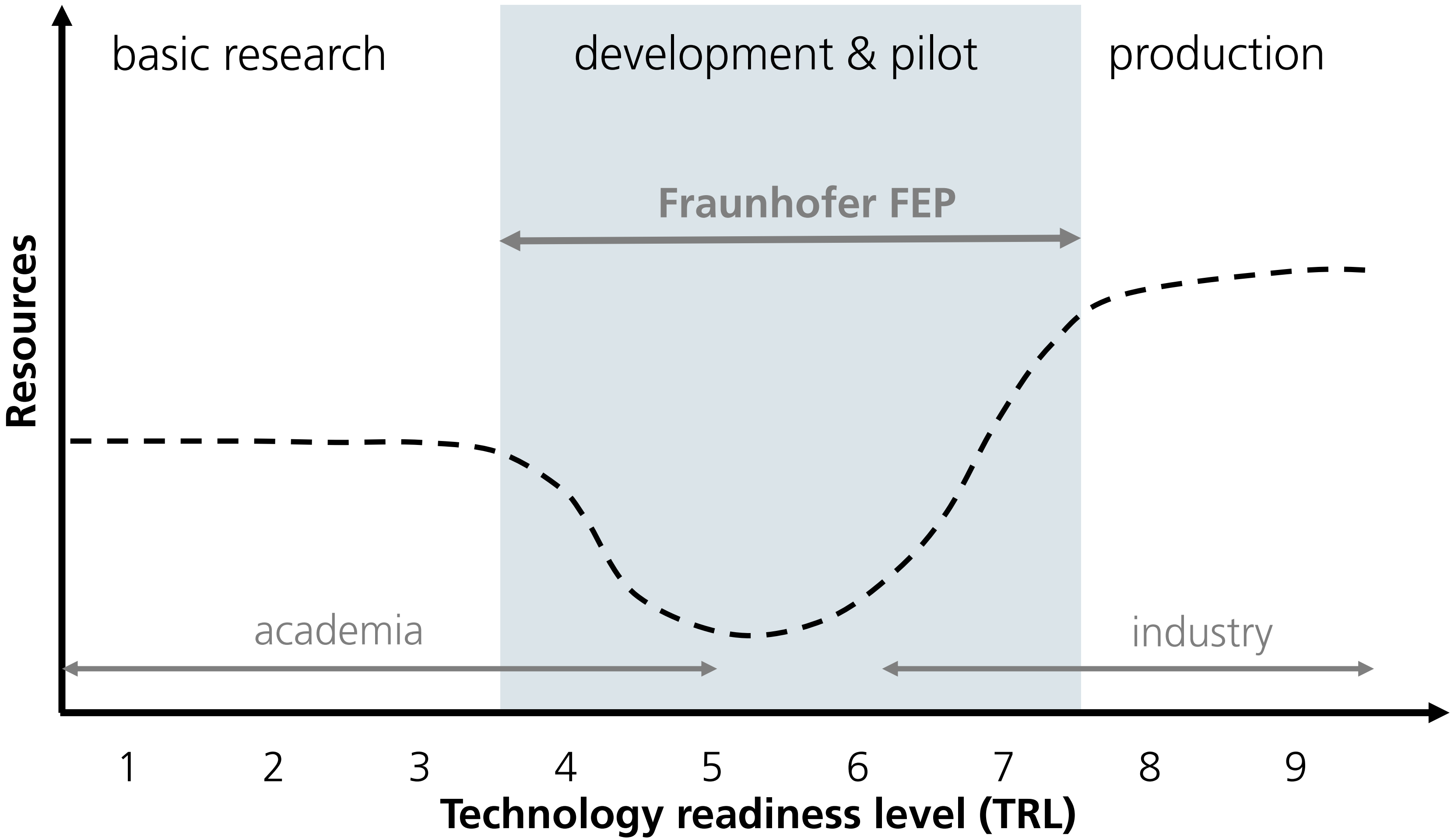
OLED lighting



Flexible displays

Smartphone optics

…but it is partly stuck in the technological valley of death

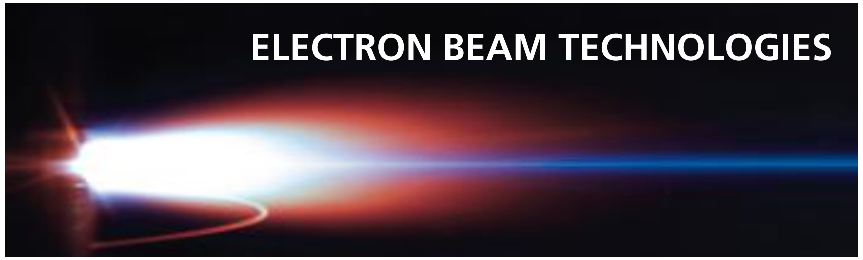


- Only a few flexible glass applications already reached TRL 8-9
- Mechanical reliability during production is one of the main challenges
- Research focus at FEP: TRL 4-7

In imitation of REHVA Journal 03/2015 p.58

Fraunhofer FEP

Core Competencies of Fraunhofer FEP



Material properties of flexible glass along the process chain

Publicly funded project *CUSTOM*

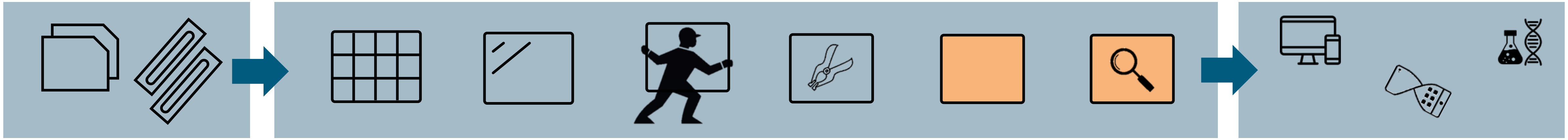
- Identification of the most crucial process steps to prevent glass fracture due to limited edge strength or glass durability
- Correlation of cutting techniques, coating process parameters etc. with fracture strength and fatigue behavior
- Results can be used to define parameter fields for reliable processing
  - suitable role diameters for winding
  - adequate contact pressure during handling
- Industrial advisory committee consists of 14 partners along the whole process chain

Federal Ministry for Economic Affairs and Energy
AiF – CUSTOM
(Grant no. 21708 BR)

Material properties of flexible glass along the process chain

Advisory committee

raw materials | functionalization | products



SCHOTT

MDI Advanced Processing GmbH

robeko

VON ARDENNE

Fraunhofer IMWS

SeeReal Technologies

3D MICROMAC

ProTec Carrier Systems GmbH

Fraunhofer FEP

CODIXX

AMG Titanium Alloys & Coatings

GfE

Müller

Adenso

YUASA – YUASA SYSTEM CO., LTD.

Federal Ministry for Economic Affairs and Energy

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Fraunhofer IMWS

Fraunhofer FEP

Vacuum inline coating machine with 10 process stations

DC and PMS

PVD and PECVD

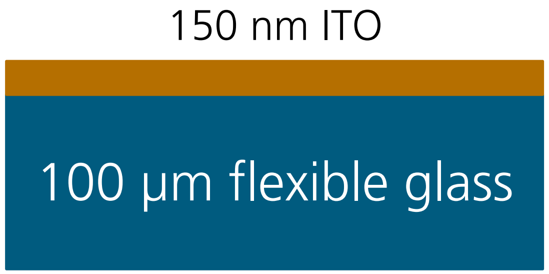
planar and rotary targets

max. 600 x 1200 mm²

pre- and post annealing
Inline flash lamp annealing

Fraunhofer FEP

ITO coatings with different thin film stress values



Deposition	room temperature	Furnace annealing (300 °C, 15 min, air)
Specific resistance	345 µΩm	255 µΩm
Thin film stress	-700 MPa	- 1100 MPa

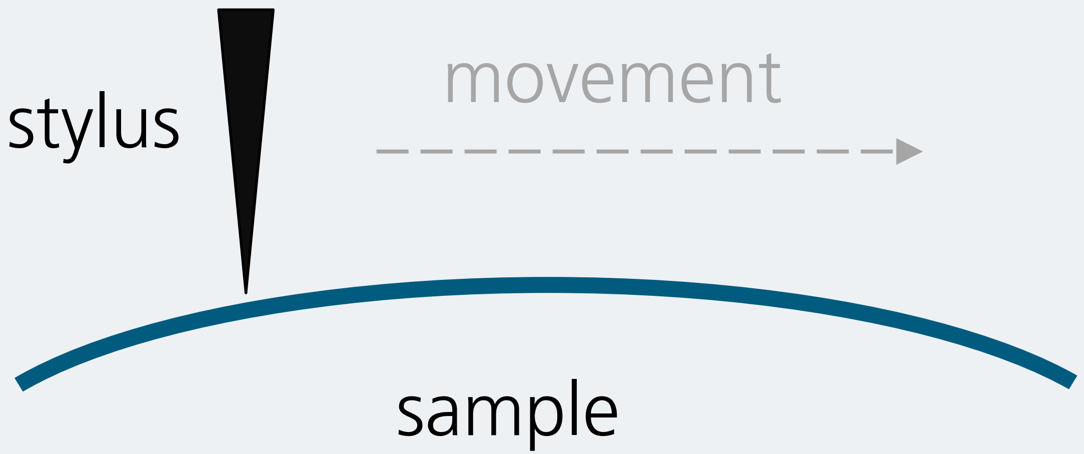
Two selected samples out of approx. 35 in the project

Thin film stress measurement

Profilometry using STONEY equation

$$\sigma = \frac{1}{6} \cdot \left(\frac{1}{R_{post}} - \frac{1}{R_{pre}} \right) \cdot \frac{E}{1-\nu} \cdot \frac{d_s^2}{d_f}$$

σ…	Thin film stress
$R_{pre/post}$…	Bending radius before and after thin film deposition
E…	Young's modulus of the substrate
ν…	Poisson ratio of the substrate
d_s…	Substrate thickness
d_f…	Thin film thickness



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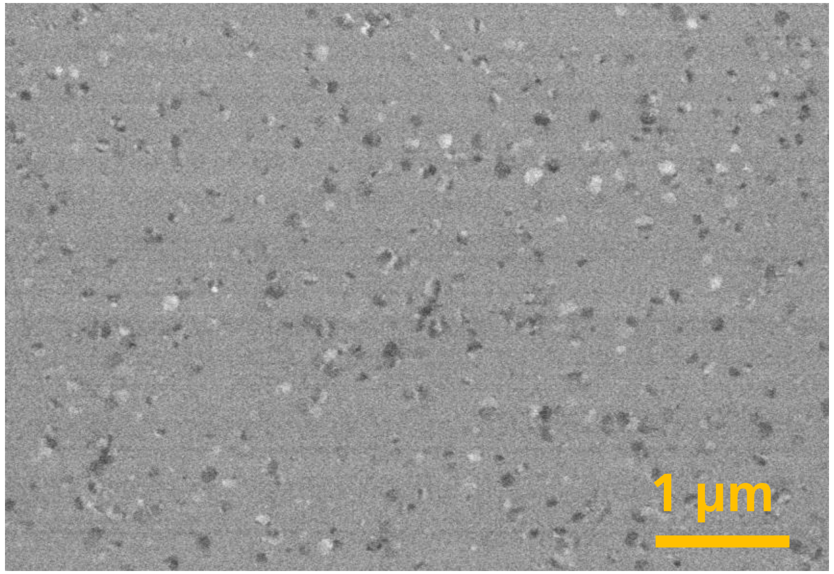
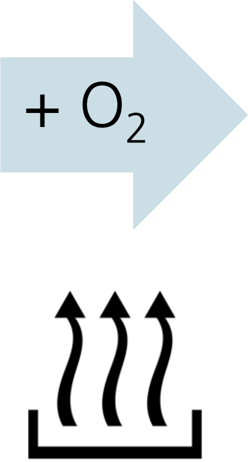
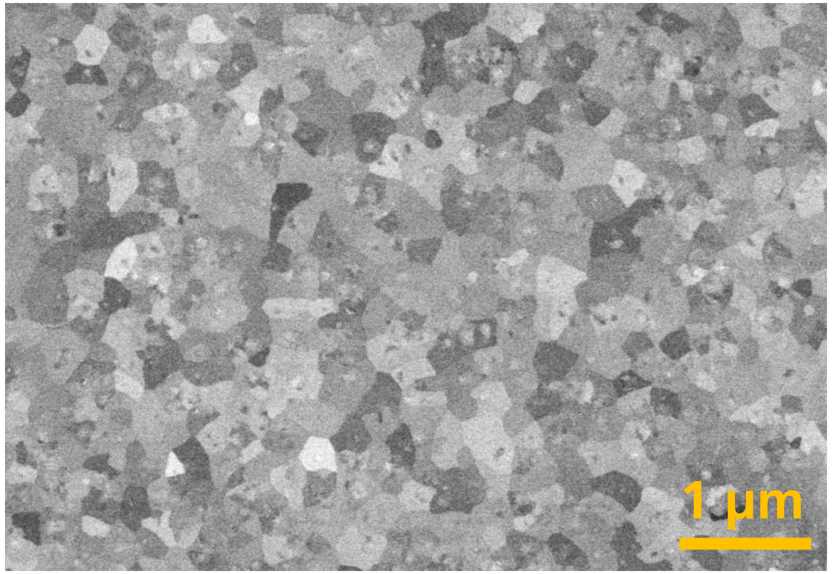
Annealing of ITO leads to full crystallization

as deposited (-700 MPa)



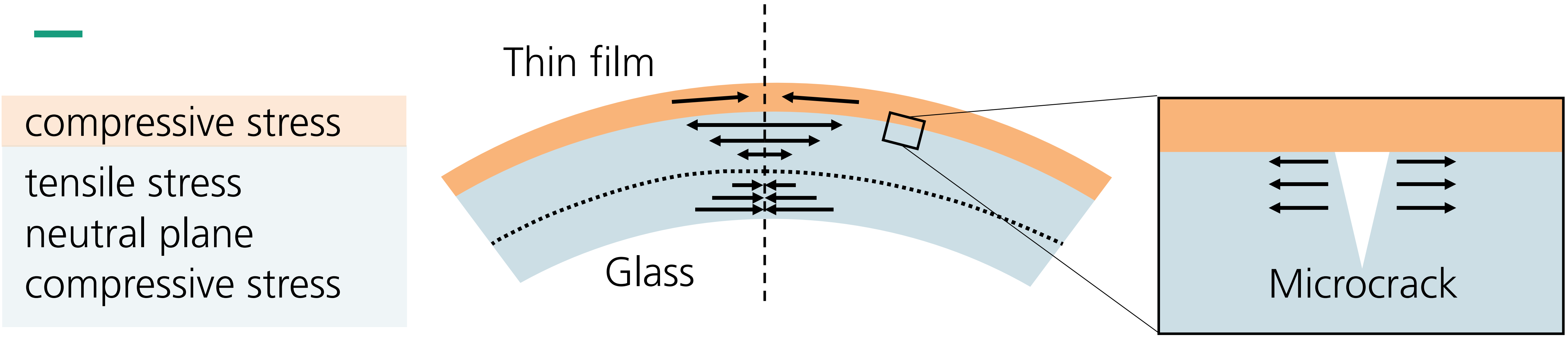


air annealed (-1100 MPa)



- Increased stress after annealing because of oxygen incorporation
- Relatively high stress values set to determine a clear influence on glass strength

Tensile stress in the glass substrate leads to crack propagation



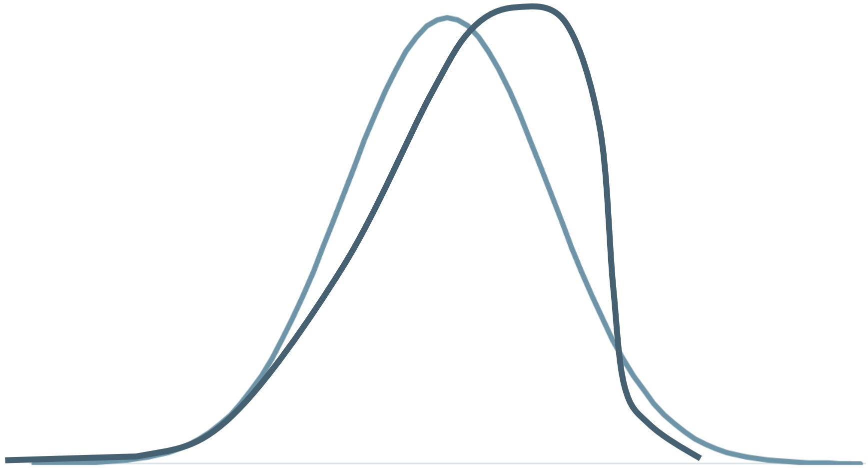
- Compressive stress in the thin film leads to a stress profile in the glass with tensile stress in the near-surface region
- Tensile stress in the glass substrate promotes subcritical crack growth i.e. it enables microcracks to propagate

Everything you need to know about glass strength (today)

1.

Failure at the weakest point, often the edge

2.



Randomly distributet, following Weibull distribution

3.

Surface strength

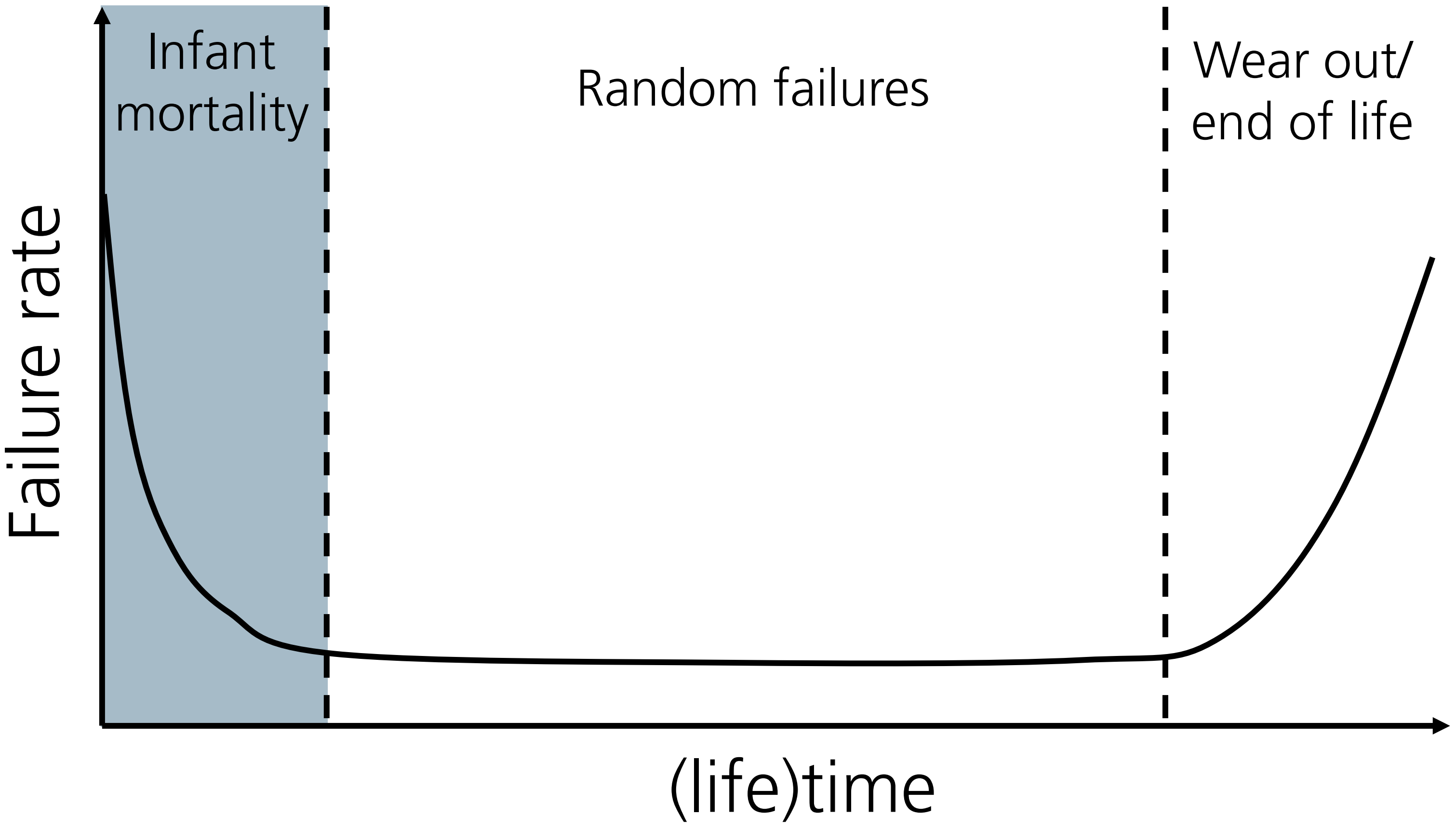
Edge strength

Fatigue

…

Product characteristic, not a material characteristic

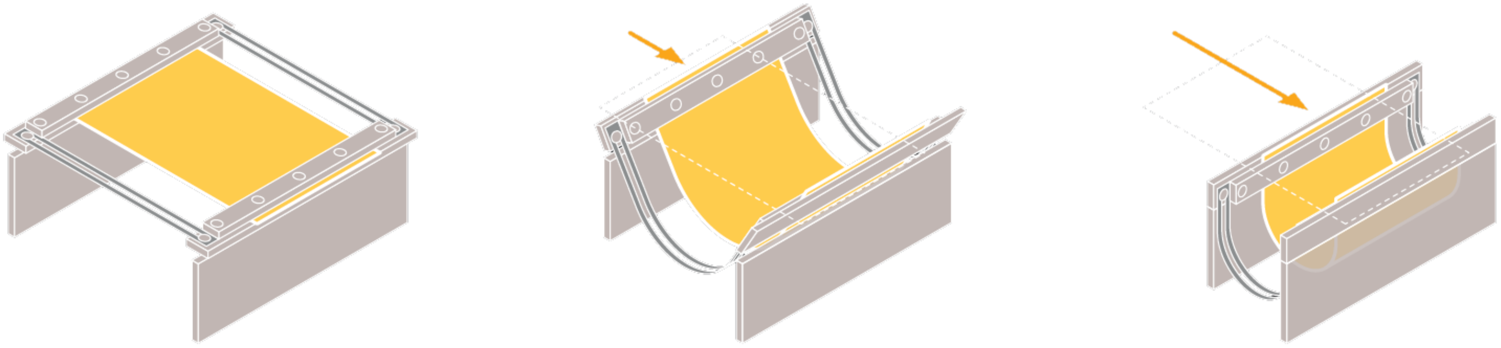
The failure rate of flexible glass during functionalization is high



- Infant mortality is highly relevant in the flexible glass process chain
- Lower infant mortality will enable viable production yields

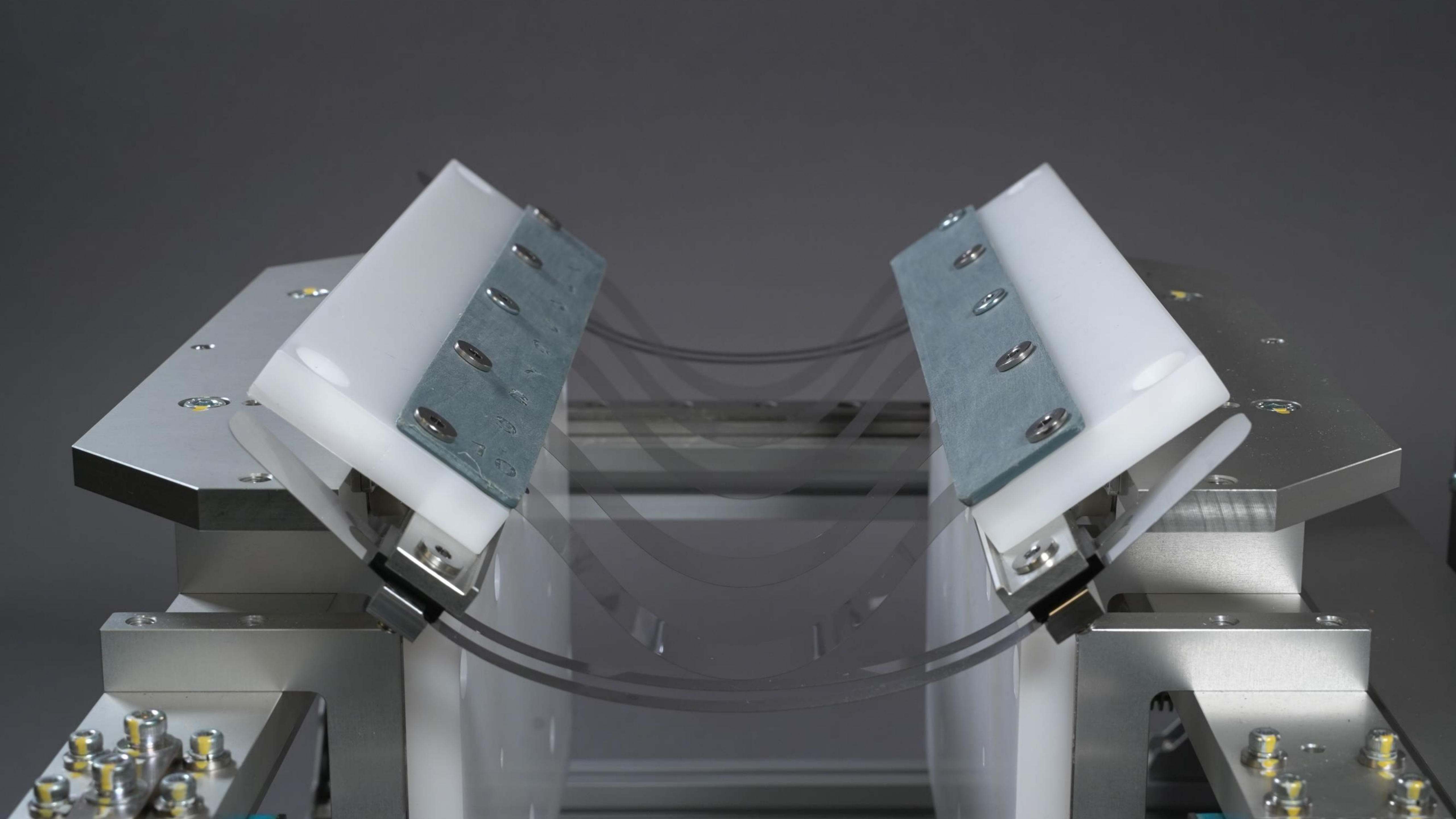
→ Research focus on early life fatigue, i.e. several 1000 load cycles

Stepwise testing to find the zone of fatigue failure



- Butterfly folding motion
- Tension-Free U-shape Folding Tester (Bayflex/ Yuasa)
- newly developed specimen holder for thin glass

- 500 bending cycles per radius, then load increase
- sample size: 30 specimens
- Test range: 130 – 500 MPa in steps of 25 MPa

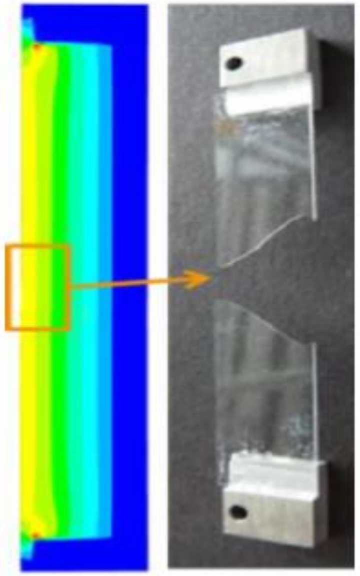


Each edge strength test generates a different stress state

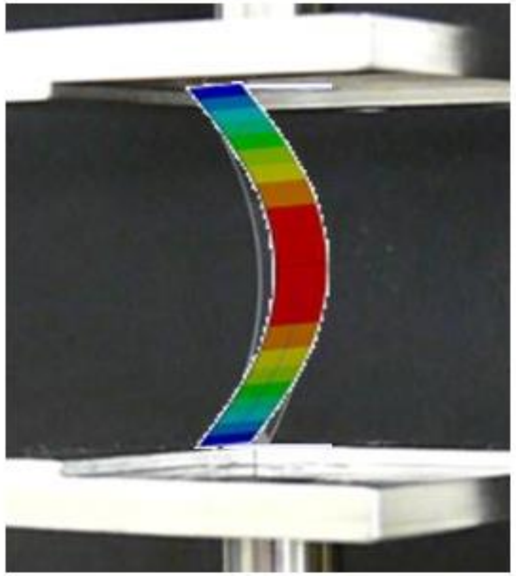
asymmetric tensile test

Intellectual property of Schott AG

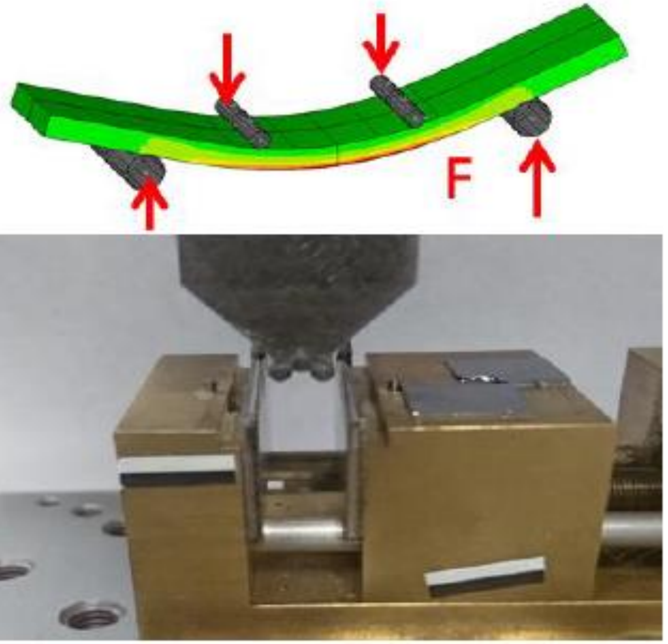
Patent No: DE 10 2014 110 856 B4



2-point bending test

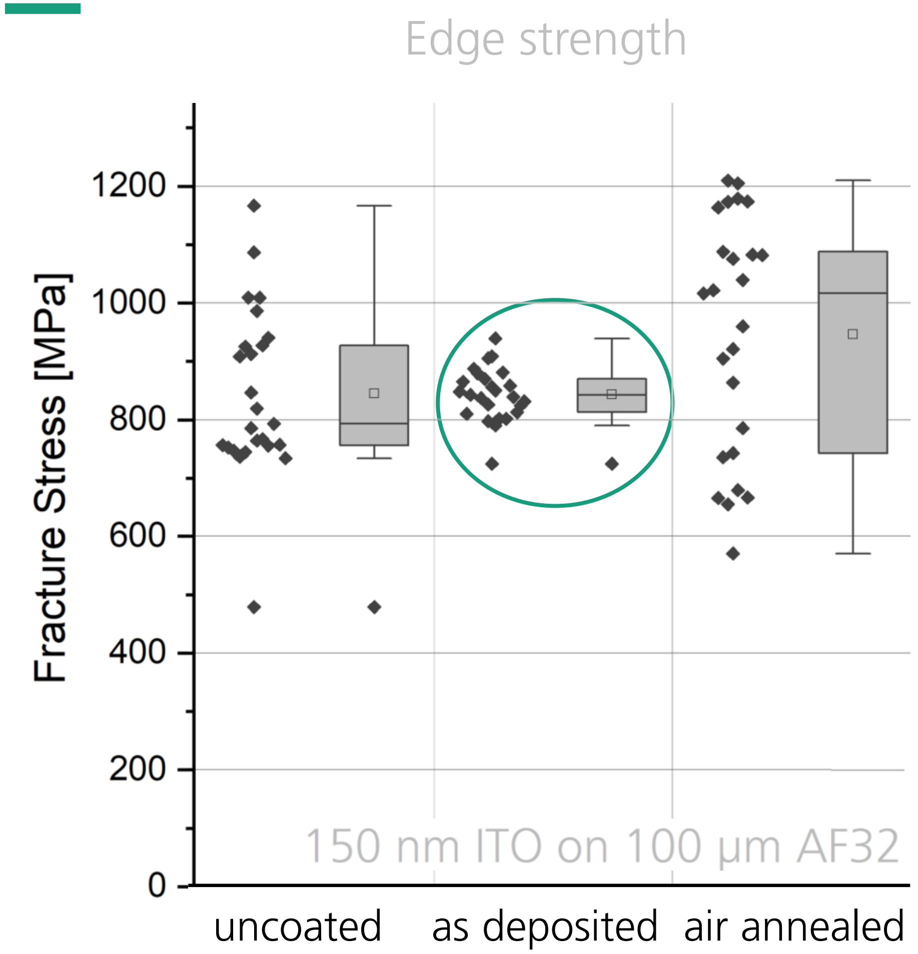


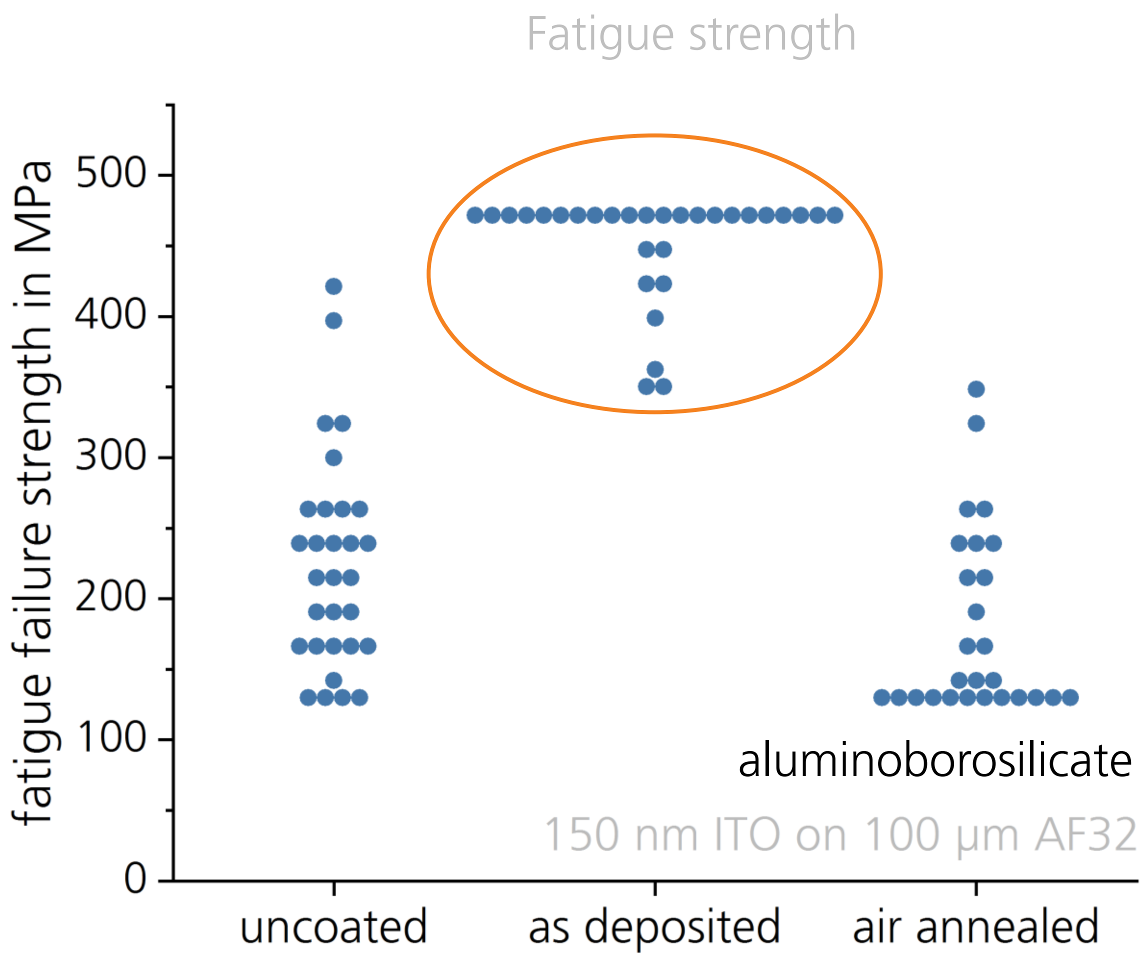
4-point bending test



- Edge strength was determined using different tests
- Here: focus on results of the 4-point bending test

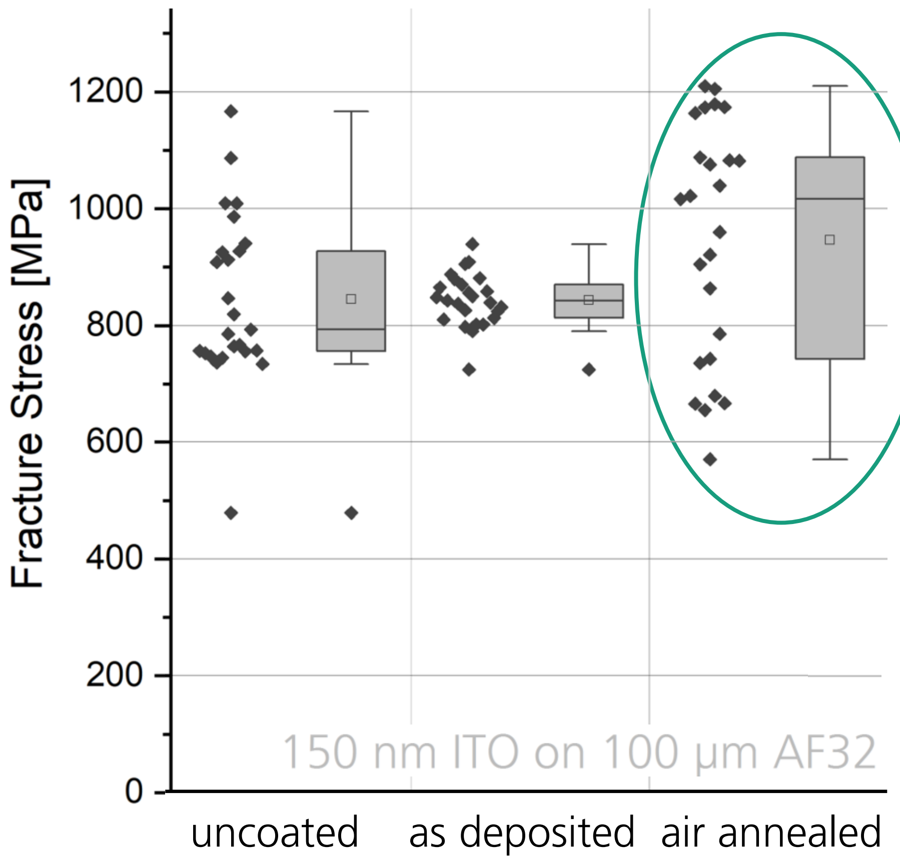
ITO coating leads to a significant (fatigue) strength increase



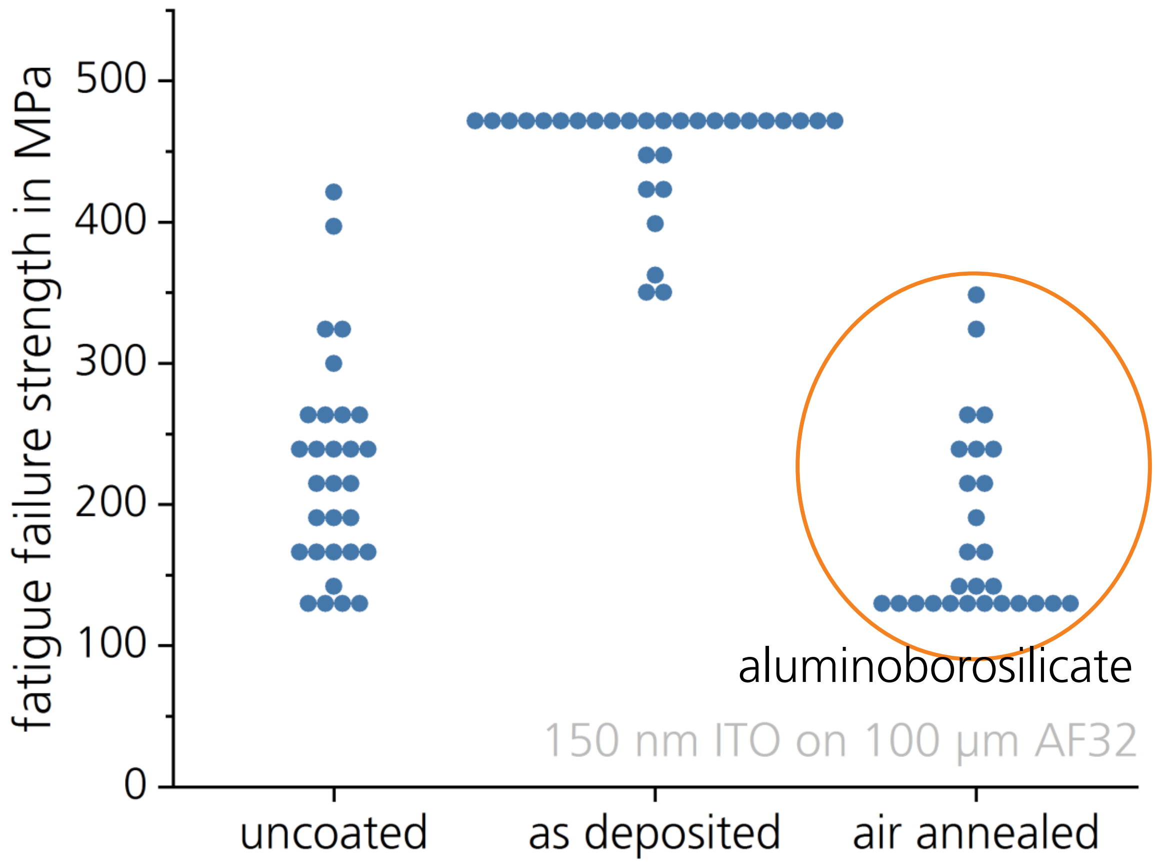


Air annealing leads to opposing effects in the two test set-ups

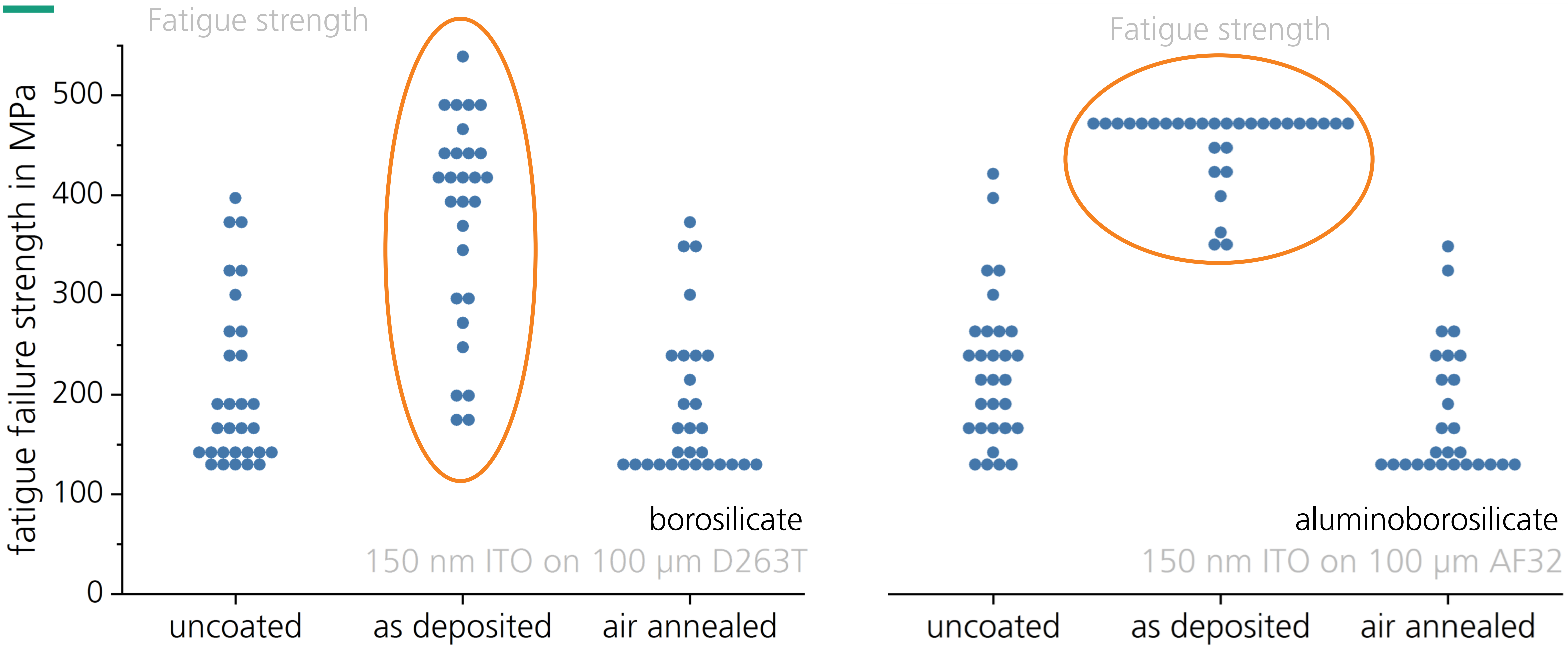
Edge strength



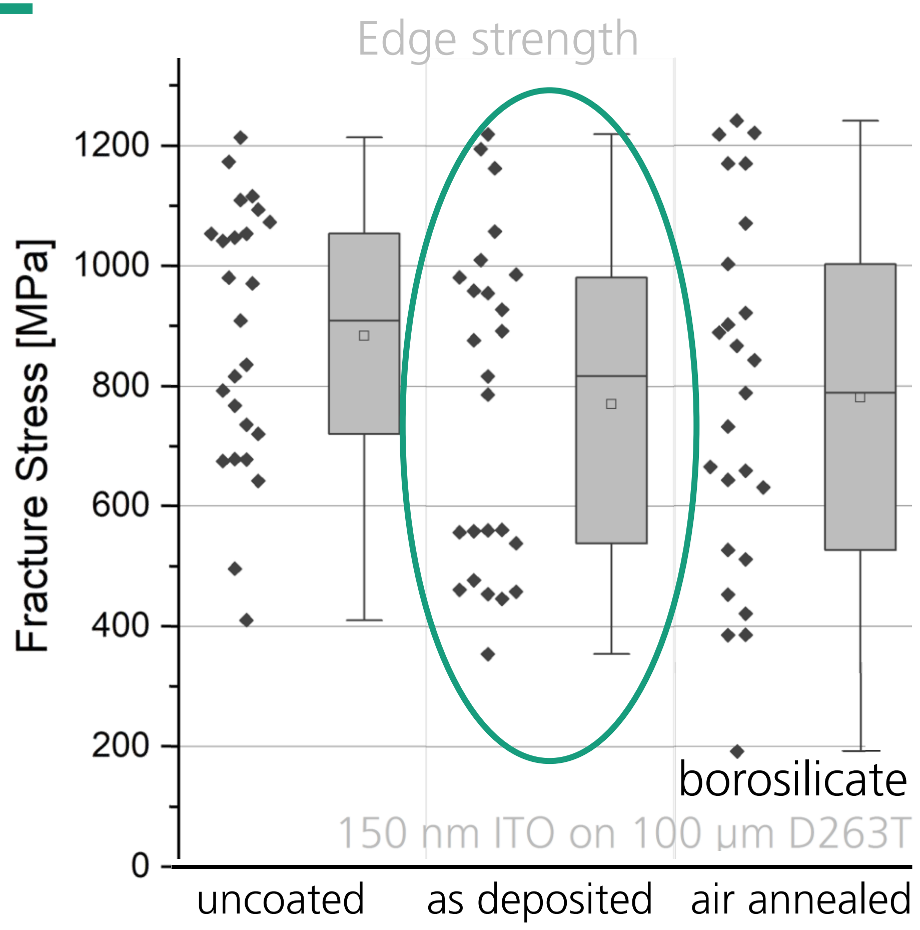
Fatigue strength

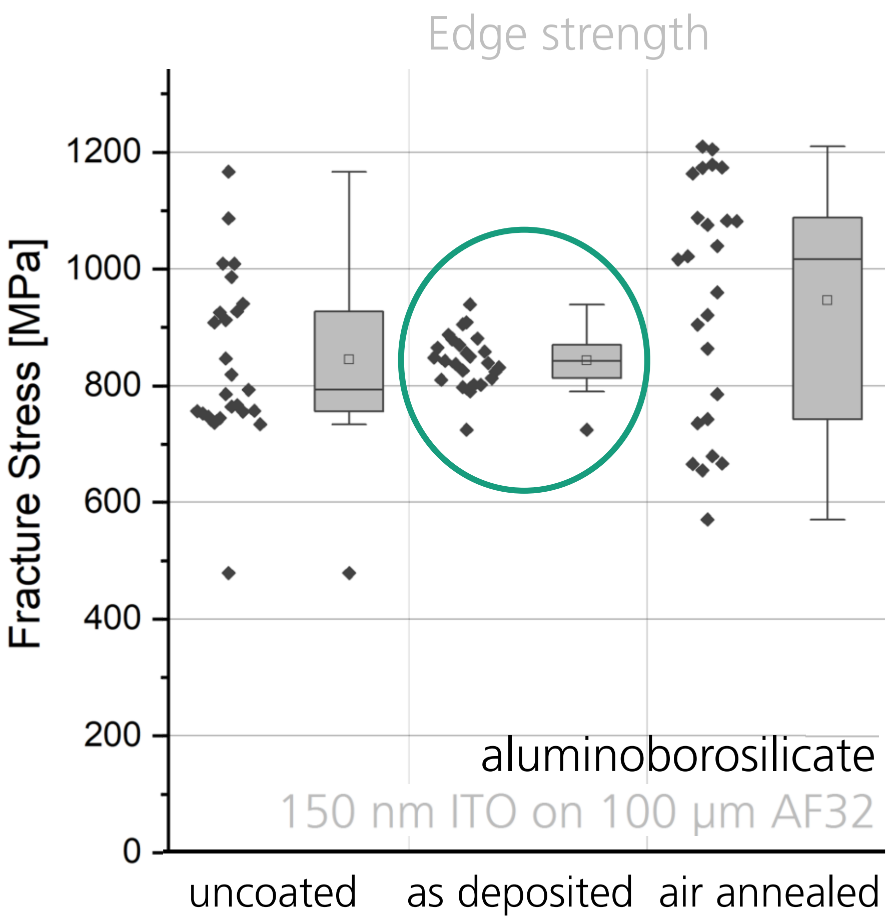


The statistical distribution differs for different glass types



…in both test setups





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Strategies for reliable flexible glass handling

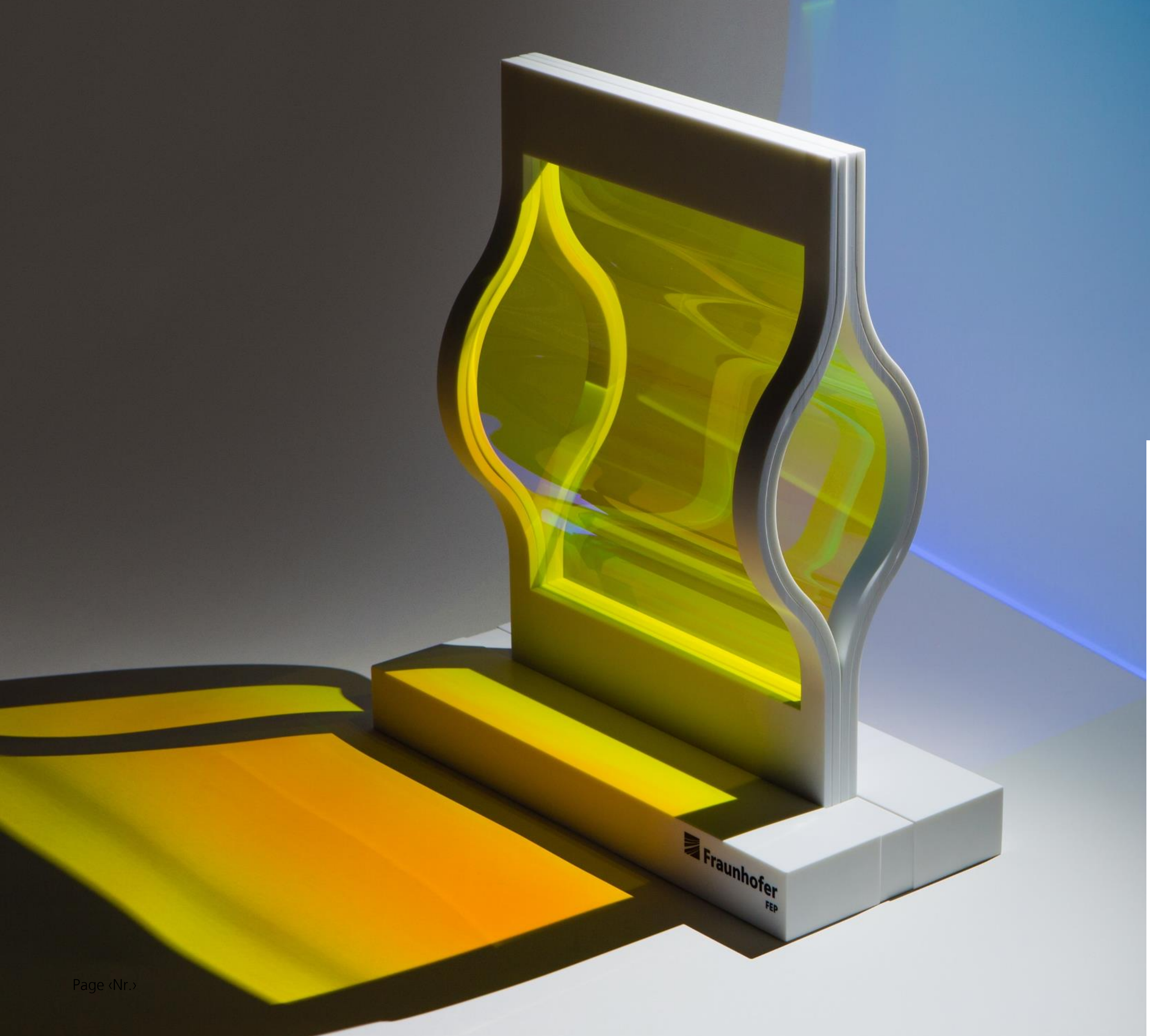
Key results

- Thin film stress influences the strength of coated flexible glass
- Coating can lead to a strength increase or decrease
- Different test methods show different results

Stress management
- Increasing importance with decreasing substrate thickness
- Crucial for process stability

Alternative annealing methods
- Vacuum annealing
- Deposition at elevated temperature levels
- Flash Lamp Annealing

Improved understanding of glass strength
- Mitigate risks during handling and functionalization
- Allow reliable processing with high yield



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EFDS

Forschungsnetzwerk Mittelstand AiF

Wiebke Langgemach
Coordination of Flexible Glass activities
Fraunhofer FEP, Dresden
wiebke.langgemach@fep.fraunhofer.de